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Abstract

Main features of gas-ionization sampling calorimeters are outlined and compared with acrylic scintillator wave-length shifter calorimeters. Calorimetry by track counting using Geiger and limited streamer modes is discussed.

Introduction

Gas ionization sampling calorimeters have become popular in the last few years - MAC detector at SLAC,[1] CLEO at Cornell,[2] and the neutrino experiment[3] at CERN have built detectors using proportional tubes for sampling energy produced by electromagnetic and hadronic cascades. At Fermilab, a shower detector using proportional wire chambers was built and tested toward developing a large system for the $\bar{p}p$ experiment at 2 TeV center of mass energy[5].

Why Gas Sampling Calorimetry

The purpose of this paper is to summarize the recent data to find an answer to this question. The usage of proportional counters in calorimetry is an old idea[6]. Proportional chambers or arrays of proportional tubes are sandwiched together generally with lead plates or iron plates to sample a small fraction of the total energy through electromagnetic cascades for electrons, positrons and gammas, and hadronic and electromagnetic cascades for the hadrons.

Some of the reasons that makes proportional drift tubes or chambers attractive for calorimetry are summarized in the following:

a. They are relatively insensitive to magnetic field as compared to photomultiplier tubes in detecting Cherenkov or scintillation light.

b. There is no Cherenkov light problem as occurs with wave-length shifter bars collecting light from scintillators.

c. It is easier to bring signals out using wires and cables than guiding light by light guides.

d. Projected detector geometry (projecting to target) can be conveniently provided by using cathode pads detecting induced signals. This is like a tower structure following the energy flow out of the target.

e. Transverse position of the electromagnetic cascades (showers) can be determined to a σ_{rms} of 1 mm easily[4]. A σ_{rms} = 7 mm was measured for hadrons of 28 GeV (Ref. 7).

f. A natural consequence of using wires, cathode strips, and pads is excellent unambiguous multishower resolution[8] of 2-5 cm obtained depending on separation efficiency.

g. Gas ionization sampling calorimeters provide reasonably good energy resolution. Some experimental numbers from electromagnetic calorimeters and the references are given in Table I. In the table the gas sampling and the acrylic scintillator and wave-length shifter devices are compared. Other types are beyond the scope of this paper. It is also a fact that acrylic scintillator is the most widely used material for calorimetry these days. The table shows that the energy resolution gets somewhat worse as the scintillator size is larger. This may be due to nonuniform light collection or low photoelectron statistics if the uniformity is achieved at the expense of photons by using some shorter wave-length filtering techniques.

The differences in energy resolution of scintillator and gas sampling devices may become unimportant at high energies. The future use of these devices is going to be in this direction. Fig. 1 shows the energy resolution multiplied by $(E/t)^{1/2}$ against the sampling thickness from several studies.

For gas sampling hadronic calorimetry, there is very little data at this time. R. L. Anderson et al. reported[1] an energy resolution of $\sigma_{rms} = .75/\sqrt{E}$ for pions of 1-15 GeV using 2.7 cm thick iron plates as converters.

h. Pulse height and gain calibration has been one of the difficulties of scintillation calorimeters. Pulse height calibration was conveniently achieved to 1-2% by the Fermilab experiment[4] using the 22 KeV line of a few Cd^{109} sources positioned on certain chambers. Those few wires monitored the gain variations due to changes in atmospheric pressure, environments temperature, and the gas compositions. This worked out very well since these quantities change very slowly in time. The gain uniformity of ±2% across the chambers and ±4% between the chambers was found to be quite possible.

i. Cost of gas sampling calorimeter systems is reasonable since the extruded aluminum or plastic drift-tube detectors are inexpensively constructed, and wires are connected together in depth resulting in a manageable number of readout channels.

Unconventional Methods

Gas sampling calorimetry in the Geiger mode[14] and limited streamer mode may become two new techniques that look promising in improving energy resolution and further easing the pulse height calibration. W. Carithers et al.,[14] LBL, has recently studied the Geiger mode of operation and found an energy resolution of $\sigma \simeq 0.12/\sqrt{E}$ for electron energies up to 5 GeV. Above this energy, the detector showed saturation effects which may be due to the fact that in the Geiger chamber there were nylon wires orthogonal to the signal wires with a spacing of 1 cm, thus limiting the Geiger spread to 1 cm along the wire. Within this limit, the pulse height would be the same for multiple tracks as for a single track.

Recently investigating pulses from a drift tube, the author noticed that large pulses of uniform height may occur when the avalanche size exceeds 8×10^6 electron-ion pairs in a gas mixture of 49.5% A - 49.5% C_2H_6 | 1% CH_3CH_2OH. The pulses may be called limited streamer

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Table 1

Reference	Sampling Thickness R_L	Energy Resolution σ_{rms}	$\sigma/\sqrt{t}$	Size (cm)	Energy Range GeV
1	0.5	$.17/\sqrt{E}$	$.24/\sqrt{E}$	30 x 30	0.3 - 15
2	0.32	$.17/\sqrt{E}$	$.30/\sqrt{E}$	162 x 366	0.5 - 3.2
4	0.68	$.24/\sqrt{E}$	$.29/\sqrt{E}$	30 x 30	10 - 46
9	0.32	$.17/\sqrt{E}$	$.31/\sqrt{E}$	18 x 18	0.5 - 12
10	0.3	$.16/\sqrt{E}$	$.29/\sqrt{E}$	21 x 50	2 - 10
11	0.37	$.092/\sqrt{E}$	$.15/\sqrt{E}$	10 x 10	0.5 - 2
12	0.35	$.133/\sqrt{E}$	$.22/\sqrt{E}$	20 x 50	5 - 10
13	0.62	$.13/\sqrt{E}$	$.165/\sqrt{E}$	20 x 20	$\leq$ 80

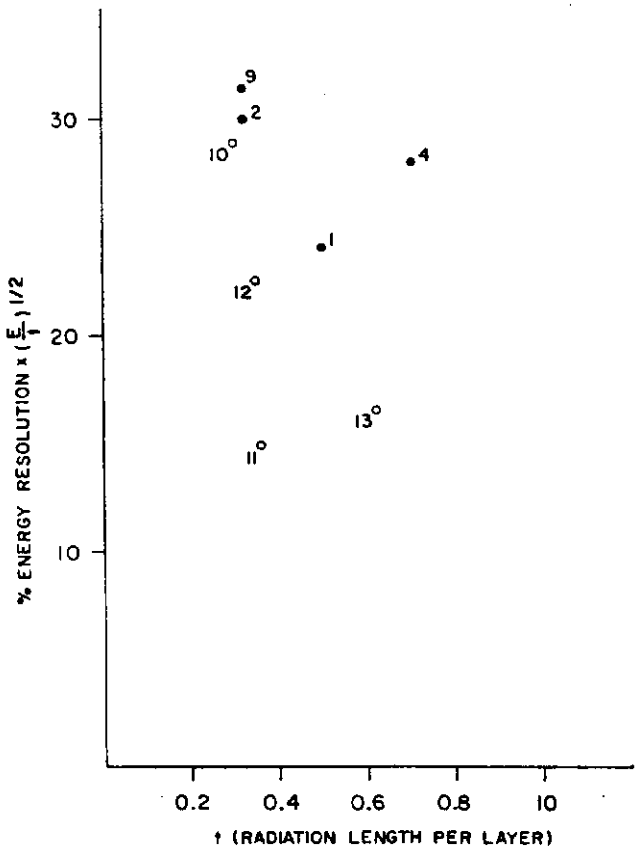

Fig. 1. Energy resolution results from several studies. Acrylic scintillator results are indicated by small circles (o) and gas sampling results are indicated by large dots (•). The studies are referenced by the numbers shown.

pulses. The cross section of the drift tube was 1.2 x 1.2 cm^2, and the anode wire was 100 μm thick. Fig. 2 shows the pulses directly obtained from the wire into 50 Ω (oscilloscope picture of Tektronik 485 with no amplifier). The pulse height distribution of the pulses from 5.9 keV x-rays of Fe^{55} and the cosmic ray pulses are shown in Figs 3a and 3b, respectively. In this case, pulses are not proportional to the energy unlike what is seen by G. D. Alexeev et al.[15] The Landau distribution expected from cosmic rays becomes Gaussian-like. Double streamers may be occurring for those cosmic rays which go through the tube at some angle.

Second streamers occurring sometime later than the first do not give rise twice the pulse height for the reason indicated in Fig. 4. The double streamers did result in twice the pulse height as the single streamer in charge sensing mode, as will be shown further in the text. High voltage dependence of the pulse height in the proportional and the limited streamer regions is shown in Fig. 5. It increases very slowly in the limited streamer region as the high voltage is increased. There is a sharp transition from the proportional region to limited streamer region above the avalanche size of 8 x 10^6 electrons.

Cosmic rays were used to investigate the minimum space requirement for producing double streamers along a wire. A pair of small scintillator telescopes were used for limiting the cosmic ray angles which provided a trigger for a Le Croy QVT. Fig. 6 shows that three or more streamers may occur within the projected length of 6 mm along the anode wire within a 300 nsec time interval. To obtain this, high voltage was kept high, 3300 V. The result indicates that two streamers can occur within 2 mm along the wire, and some of the electron clusters are large enough to reach the critical avalanche size. The pulse height resolution for multiple streamers is expected to get better if multiple tracks are detected simultaneously.

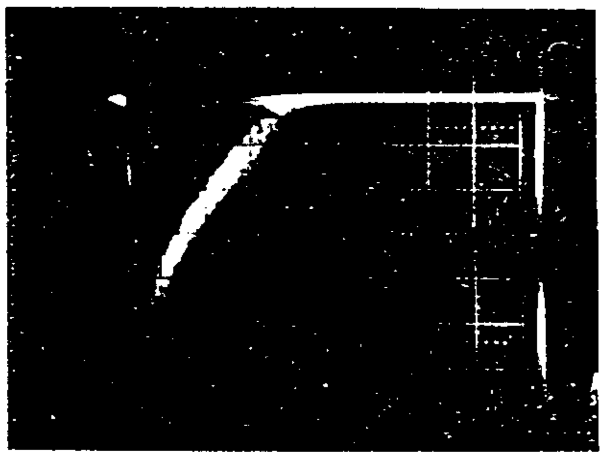

Fig. 2. The limited streamer pulses observed on an osciloscope screen directly across 50 Ω. Horizontal scale is 50 nsec/div and vertical scale is 10 mV/div.

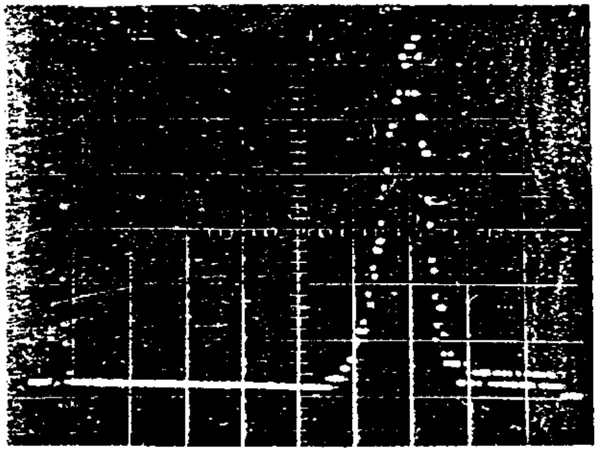

Fig. 3a. The pulse height distribution of the 5.9 keV x-rays from an Fe^{55} source.

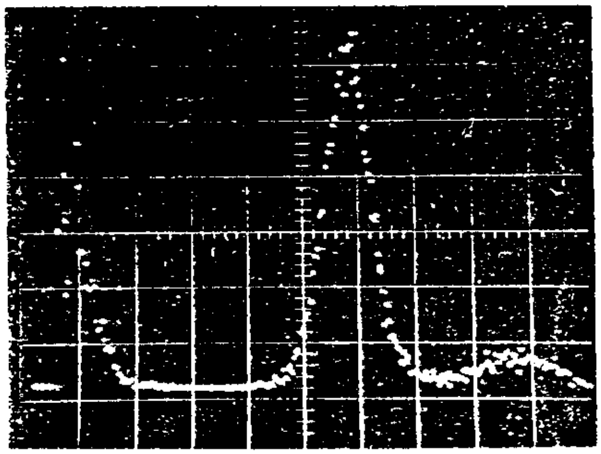

Fig. 3b. The pulse height distributions of the cosmic rays. The pulse height analyzer (Le Croy QVT 3001) was used in peak sensing mode for the pictures.

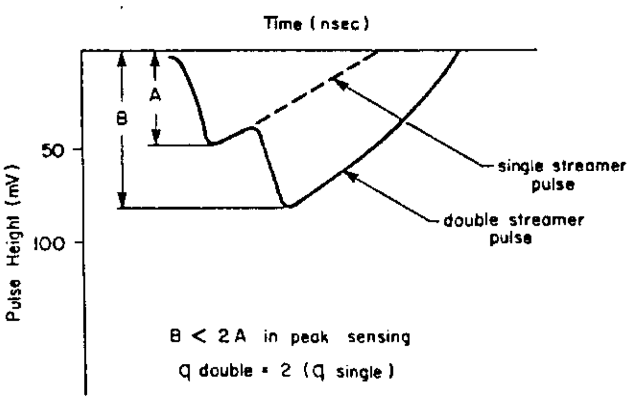

Fig. 4. A sample display of a single and double streamer pulse across a 50 Ω impedance.

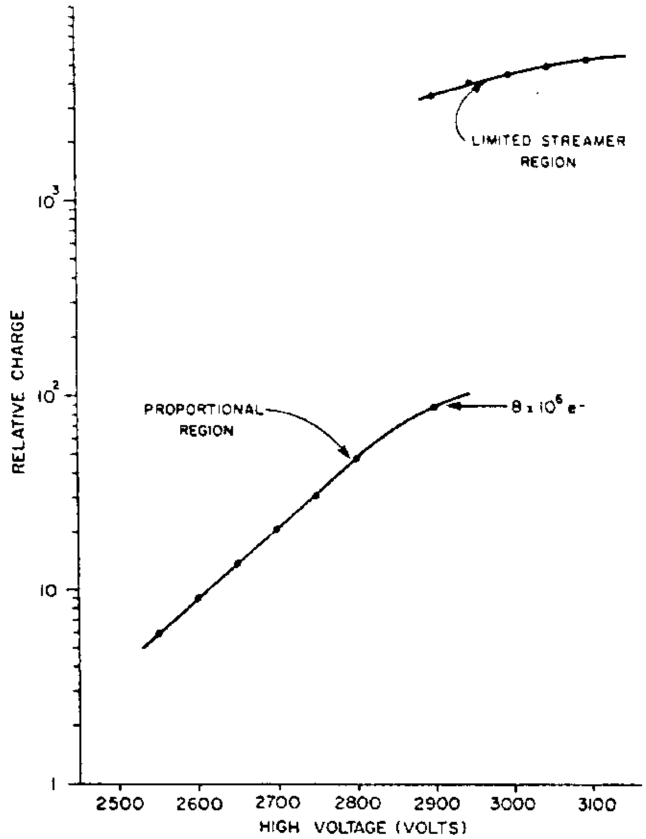

Fig. 5. High voltage dependence of the mean pulse height of the 5.9 keV line in the proportional and the limited streamer regions.

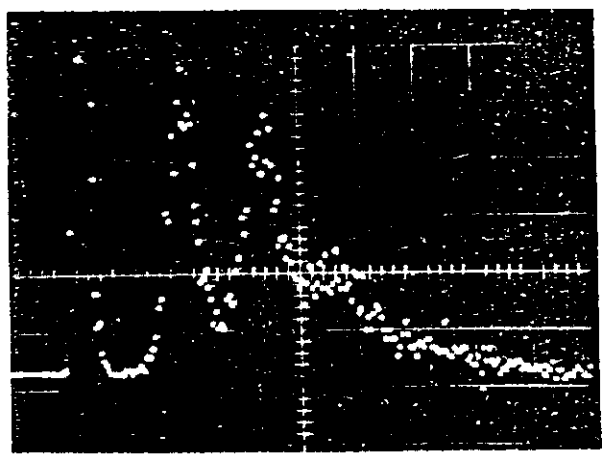

Fig. 6. A picture of multiple streamers within 6 mm along the anode wire. Single, double, and triple streamers are resolved.

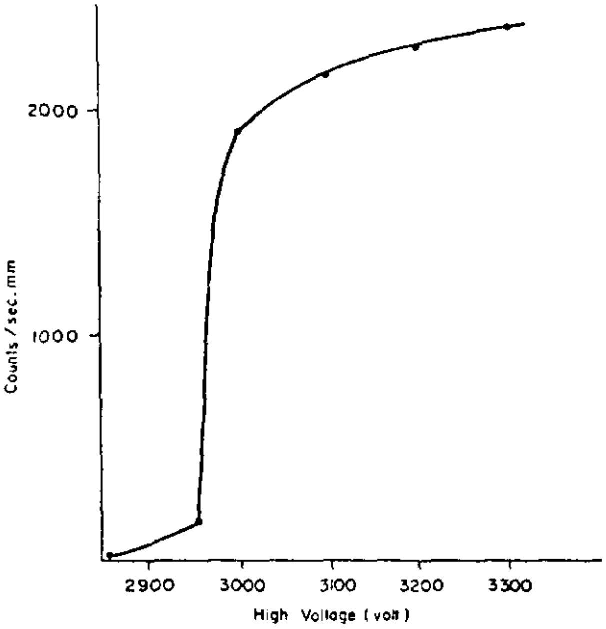

Fig. 7. Rate versus the high voltage using a 1 mm collimation slit and a 5.9 keV x-ray source. It indicates that rate limitation is not reached with this source strength.

An attempt was made for studying rate capability of the drift tube in the limited streamer mode. A 1 mm wide collimated source of 5.9 keV x-rays from Fe^{55} was used for the test. Fig. 7 shows the rates against the applied high voltage. It shows that the rate capability is better than 2×10^4/sec cm per wire. Due to the lack of a high energy beam and higher intensity source, the upper limit is not known at this time. It is clear that this is a different phenomena than the phenomena reported earlier by S. Brehin et al.[16] where the rate capability was two orders of magnitude lower than this case.

Conclusions

a. Track counting in the limited streamer mode is expected to improve energy resolution in gas calorimetry owing to the fact that the Landau tail is eliminated.[14] The improved resolution in the Geiger mode[14] tends to support this belief.

b. Drift tube size of 3-4 mm would be better for calorimetry by providing even higher rate capability with more streamer tracks per unit area.

c. At this time the author does not know at what energy of electrons or pions a saturation effect on the energy resolution may become a limiting factor for the limited streamer sampling calorimetry. This will be studied.

d. Using this technique, very inexpensive multiplicity telescopes can be made. J. K. Walker's group at Fermilab is planning to use this technique for their neutrino experiment.[18]

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